# Spin-Alignment Induced Parity Violation in the Early Universe

## A Pre-Thermal Origin Model for CMB EB Correlations

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### Abstract

This work proposes a pre-thermal origin model in which the universe begins from two motionless, cold, static effective gravitational spin fields in a flat baseline geometry. A symmetry-breaking instability introduces a spin-alignment perturbation prior to the onset of conventional thermodynamic evolution. This perturbation sources vector vorticity modes that survive through radiation domination and imprint a parity-odd signal in the cosmic microwave background (CMB). A linearized coupled system between spin-divergence perturbations and vorticity is developed, leading to a transfer function that connects the initial instability to observable CMB EB correlations. A minimal physical model is introduced, and an analytic approximation for the transfer function is derived. The model predicts a residual parity-odd amplitude in the range of ($10^{-10}$) to ($10^{-12}$), within the projected sensitivity of next-generation CMB polarization experiments.

### 1. Introduction

Standard cosmology describes the large-scale evolution of the universe through the Friedmann equations, where curvature is determined by total stress-energy content. Observations constrain the universe to be nearly flat with ( $\Omega_0 \approx 1$ ). However, the origin of this near-flatness remains an open question, often addressed by inflationary models.

This work instead considers a pre-dynamical baseline: two motionless, cold, non-interacting effective gravitational spin fields. In the absence of gradients, pressure, or stress-energy differences, the only self-consistent geometry is flat. A symmetry-breaking instability initiates motion, leading to the emergence of energy, expansion, and structure.

## 2. Spin-Alignment Instability

We introduce a scalar quantity representing spin-field divergence:

$$
\delta S \equiv \delta(\nabla \cdot \mathbf{s})
$$

At the onset of instability,

$$
A_i \sim 10^{-6}
$$

This perturbation acts as a source for vector vorticity modes, introducing a parity-odd component into early-universe dynamics.

## 3. Linearized Evolution Equations

$$
\delta S_k'' + 2\mathcal{H} \delta S_k' + (c_s^2 k^2 + a^2 m_s^2 + a^2 \Gamma_s)\delta S_k = a^2 \alpha \rho , \omega_k
$$

$$
\omega_k' + 2\mathcal{H} \omega_k + \nu k^2 \omega_k = \beta \delta S_k
$$

## 4. Transfer Function to Recombination

$$
T_{(\omega S)}(k,\eta_*) =
$$

$$
\int_{\eta_i}^{\eta_*}
\beta(k,\eta') \exp\left[-\int_{\eta'}^{\eta_*}
\left(2\mathcal{H} + \nu k^2\right)d\eta''\right] d\eta'
$$

$$
\omega_k(\eta_*) = T_{(\omega S)}(k,\eta_*) \delta S_k(\eta_i)
$$

Superhorizon modes experience partial source-driven growth that counteracts Hubble dilution.

## 5. Damping and Residual Amplitude

$$
A_r = A_i \times D
$$

$$
A_i \sim 10^{-6}, \quad D \sim 10^{-4} - 10^{-8}
$$

$$
A_r \sim 10^{-10} - 10^{-14}
$$

## 6. CMB Parity-Odd Signature

$$
C_\ell^{EB} = 4\pi \int \frac{dk}{k} , P_{\delta S}(k), T_{(\omega S)}^2
\Delta_\ell^E \Delta_\ell^B
$$

$$
\frac{C_\ell^{EB}}{C_\ell^{BB}} \sim 10^{-10} - 10^{-12}
$$

## 7. Discussion

Flatness emerges naturally without requiring inflation. The spin-alignment instability provides a mechanism for parity violation while preserving isotropy.

Since ($A_r \ll 10^{-5}$), vector modes remain subdominant and do not disturb acoustic peaks, ensuring compatibility with ΛCDM observations.

## 8. Conclusion

A pre-thermal spin-alignment instability provides a testable origin for parity-odd CMB signatures, with amplitudes near the detection threshold of next-generation experiments.

## 9. Minimal Physical Model

$$
\mathcal{L} =
-\frac{1}{2}(\partial_\mu s^\nu)(\partial^\mu s_\nu)
-\frac{1}{2}m_s^2 s^\mu s_\mu
* \frac{\lambda}{2}(\nabla \cdot s),\omega^\mu s_\mu
$$

$$
\beta \propto \lambda
$$

$$
P_{\delta S}(k) = A_i^2 \left(\frac{k}{k_0}\right)^{n_s-1}, \quad n_s \approx 1
$$

## 10. Approximate Transfer-Function Solution

$$
\omega' + \frac{2}{\eta}\omega = \beta A_i
$$

$$
\omega(\eta) = \frac{\beta A_i \eta}{3} + \frac{C_1}{\eta^2}
$$

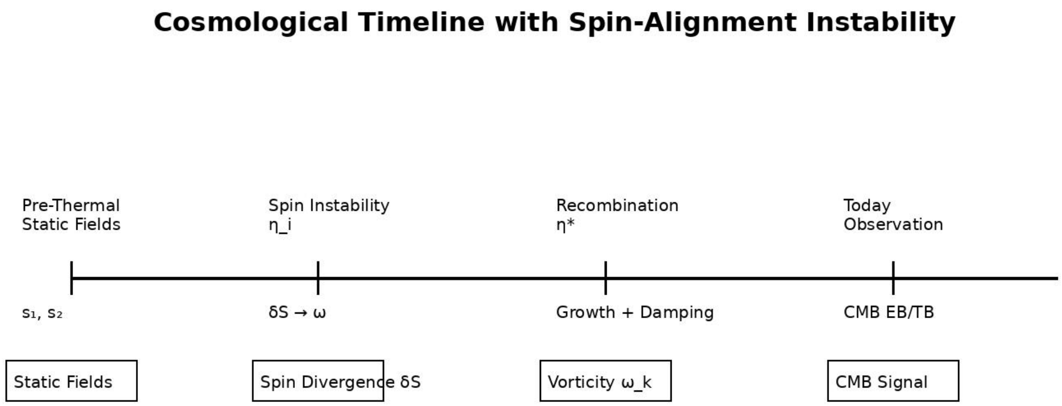
$$
T_{(\omega S)}(k,\eta_*) \approx \frac{\beta \eta_*}{3}
$$

This linear growth reflects cumulative sourcing during radiation domination.

## References

Guth (1981), Silk (1968), Planck (2018), Hu & White (1997), Kamionkowski (2009), CMB-S4, LiteBIRD, BICEP/Keck, and related parity-violation literature.

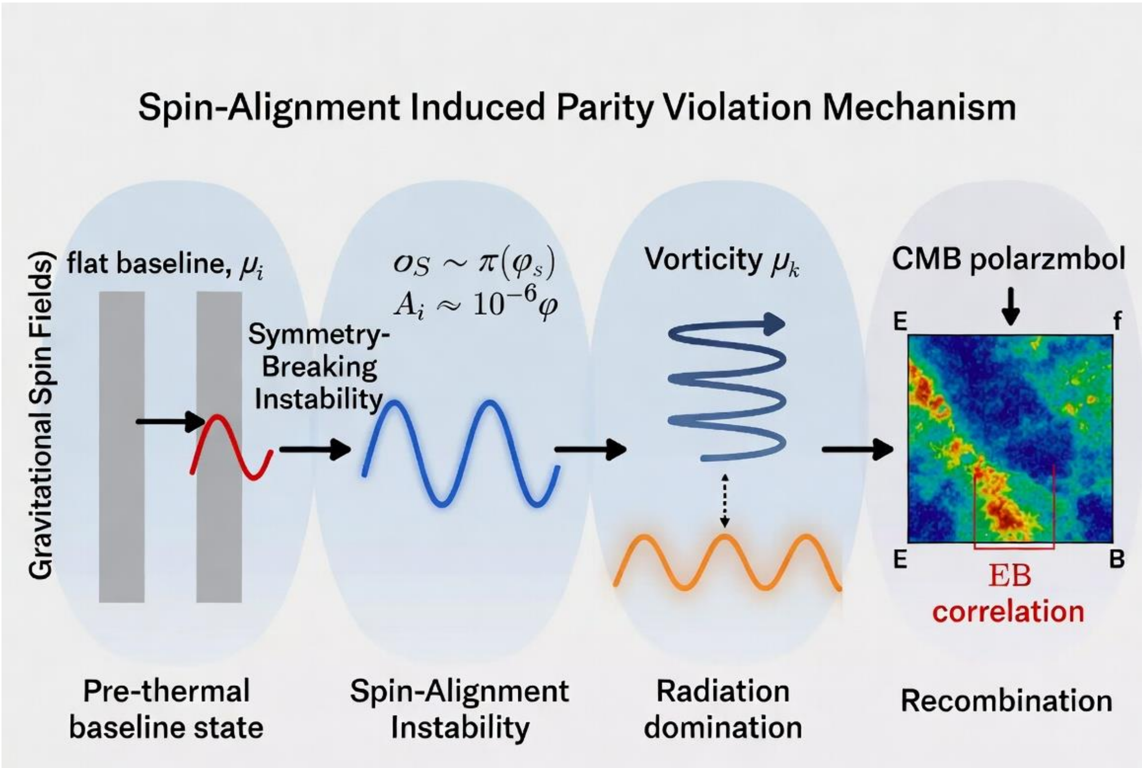
**FIGURE 1**




Cosmological timeline illustrating the proposed pre-thermal spin-alignment instability. Two initial motionless gravitational spin fields define a flat baseline geometry. A symmetry-breaking event at conformal time ( \eta_i ) generates a spin-divergence perturbation ( \delta S ), which sources vorticity modes during radiation domination. These modes undergo partial growth and damping before recombination at ( \eta_* ), leaving a residual parity-odd imprint in the CMB polarization (EB/TB correlations).

**FIGURE 2**:

Schematic of the spin-alignment induced parity-violation mechanism.




The pre-thermal baseline consists of two motionless gravitational spin fields in a flat geometry. A symmetry-breaking instability generates a small spin-divergence perturbation $\delta S \equiv \delta(\nabla\cdot\mathbf{s})$ with amplitude $A_i \sim 10^{-6}$. This sources vector vorticity modes $\omega_k$ that grow during radiation domination and survive to recombination ($\eta_*$). The resulting vorticity imprints a parity-odd EB correlation in the CMB polarization field (highlighted in the rightmost panel). The diagram illustrates the full causal chain from the pre-thermal initial state to the observable parity-odd signal.